

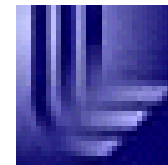
US FAST IGNITION RESEARCH



OVERVIEW and PLANS for FY09-10



R. Betti
FY10 Budget
Planning Meeting
Gaithersburg, MD,
March 11-12, 2008



OFES developed a strong program in Fast Ignition research

- Broad based US partnership through FI-ACE & FSC
 - University (UR, OSU,UCD,UCSD,UNR),
 - National laboratory (LLNL, SNL, LANL),
 - Industry (GA) research partnership
 - Coordinated with NNSA activities
- International Collaborations
 - FIREXI (Osaka)
 - Vulcan PW (RAL)
- Complete science capability
 - Modeling - hydro, hybrid PIC, PIC
 - Diagnostic development
 - Target development & fabrication

Short-term goal (FY08-10) is physics basis of FI

Mid-term goal (FY10-12) is integrated cryo-experiments

FY08-10

Fuel Assembly

- FI point design
- Uniform high density close to cone tip

Ignitor energy creation and transmission

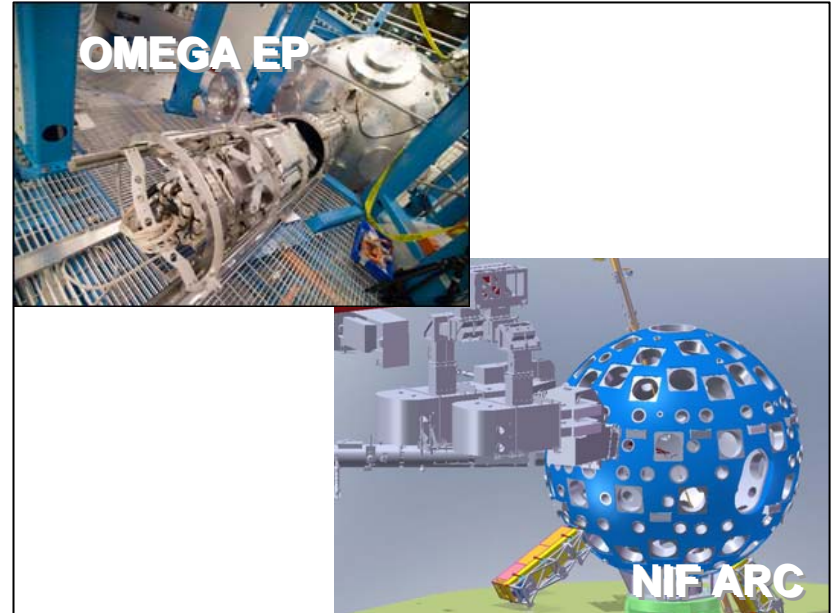
- Laser coupling to electrons and protons
- Channeling
- Symmetric shock

Integrated modeling

- Benchmarked for FI relevant parameter
- Integrating hydro, hybrid PIC, PIC

**Validate the
physics basis
for Fast Ignition**

FY10-12

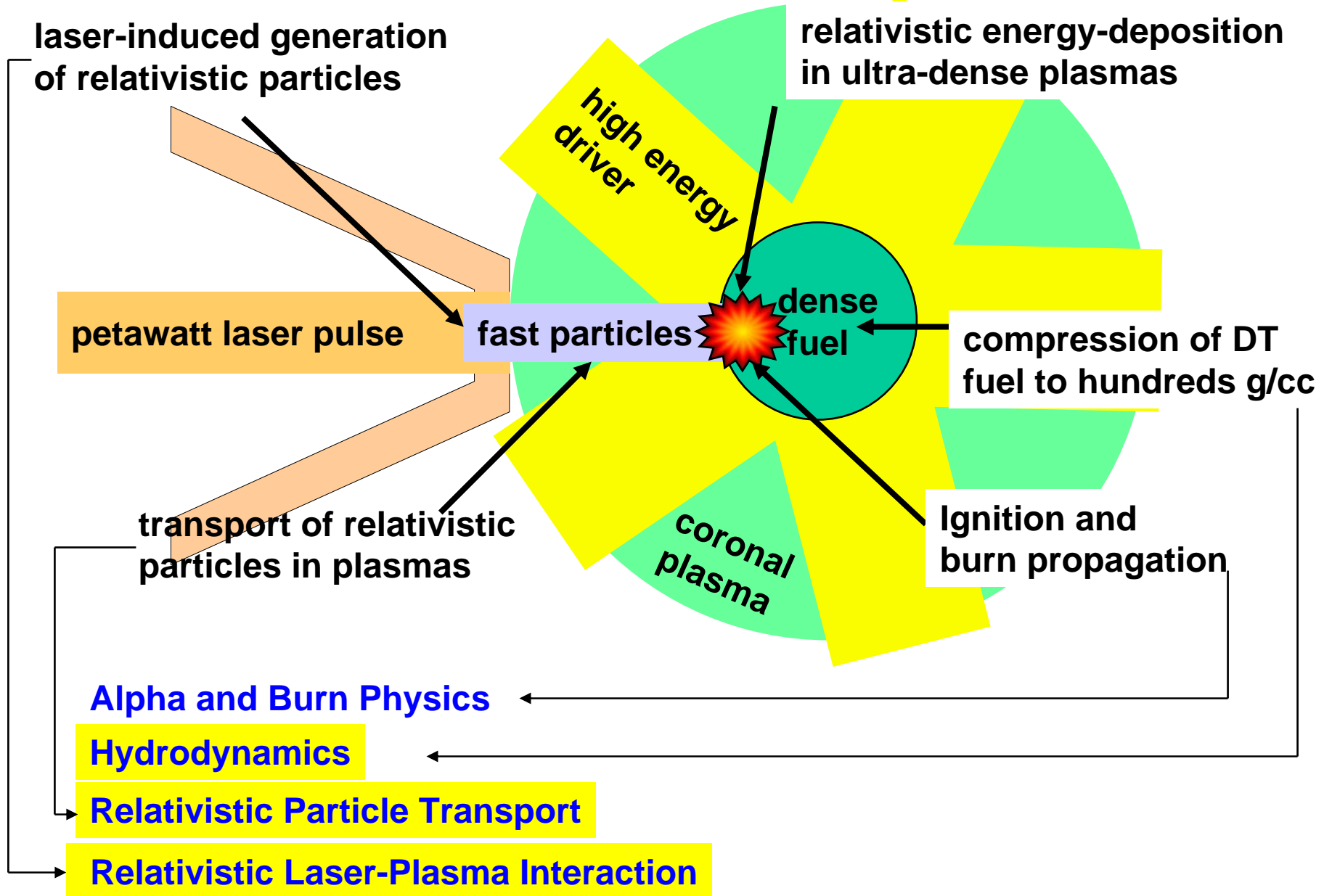


**Use point designs and
ignitor physics to field
integrated cryogenic
experiments**

US Fast Ignition Program: Highlights in '07-'08

- **OFES funding for Fast Ignition in FY08: \$6.5M**
- **Funding Breakdown: Fusion Science Center \$1.094M,
Advanced Concept Exploration \$3M
New Initiative at LLNL \$2.3M
Other (LANL, UNR, UT, PPPL) \$0.16M**
- **Much interest worldwide: '94 Tabak's is most cited PoP paper**
- **>22 refereed papers published or submitted: Science (1); Phys. Rev. Lett. (7);
Phys. Plasmas (13); J. Comp. Phys. (1); Rev. Sci. Instrum. (2)**
- **>10 invited talks: APS (6); IFSA (3); Anomalous Absorption (1)**
- **Large High-Intensity Laser Facilities begin operation in '08
OMEGA-EP at U. Rochester, Texas Petawatt at U. Texas (Austin)**

Fast Ignition research requires a multi-disciplinary approach



Fast Ignition activities and plans for FY09-10

FESAC priorities – HEDP campaign – Research thrust

- Develop a basic understanding of the transport and stopping of particle beams in HEDP plasmas using PIC codes, coupled with experiments.
 - Develop basic understanding of fast particle generation for relevant intensities and pulse lengths
-
- Design targets and carry out implosion experiments to identify the optimum assembly of HEDP plasmas at densities of hundreds g/cc.

Fast Ignition:

main issues to be addressed in FY08-10

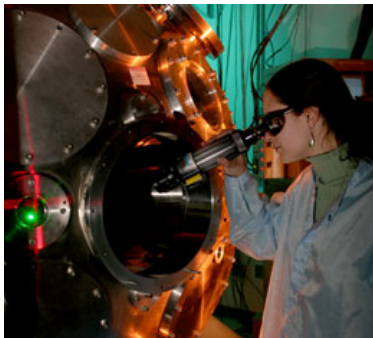
- **Fast electron or ion energy spectrum**
1-2MeV electron energies ideal for electron FI
15-25MeV protons and 0.4-0.5GeV C-ions ideal for ion FI
- **Laser-to-fast electron/ion conversion efficiency**
Higher efficiencies → smaller size PW laser required for ignition
- **Particle transport in plasmas**
What is the e-beam divergence in a plasma?
What is the ion-beam divergence in a plasma?
- **Coupling to the dense core**
How much fast-electron/ion energy will couple to the dense core in integrated FI implosions?

FY08-10 experiments will give the physics detail necessary for the point design of initial FI integrated expts in FY10/12 on OMEGA-EP and NIF-ARC

Main facilities for Fast Ignition research FY09-10

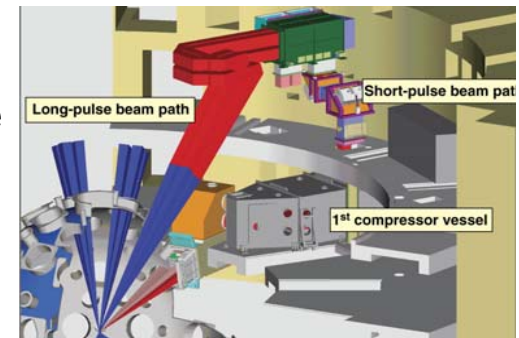
- OMEGA EP (LLE): long and short pulse, integrated experiments (2.5kJ/10ps+30kJ/4ns)

Trident



- Titan (LLNL): long and short pulse
- ZPW (Sandia): long and short pulse
- Trident (LANL): long and short pulse
- NIF-ARC (2010)

NIF-ARC



OMEGA EP



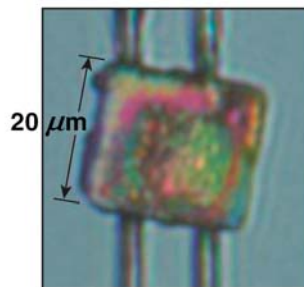
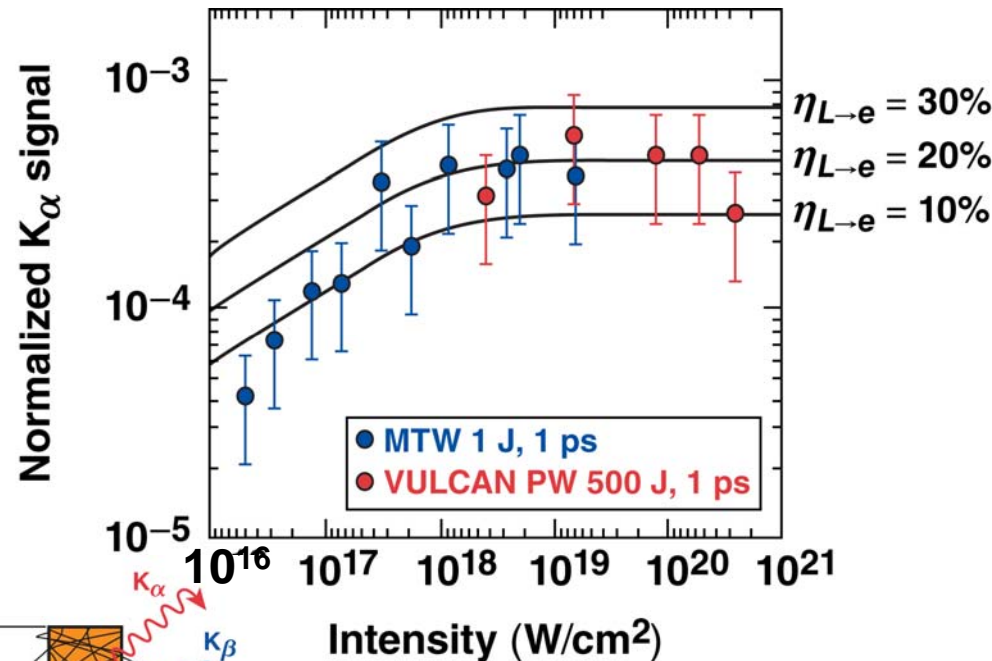
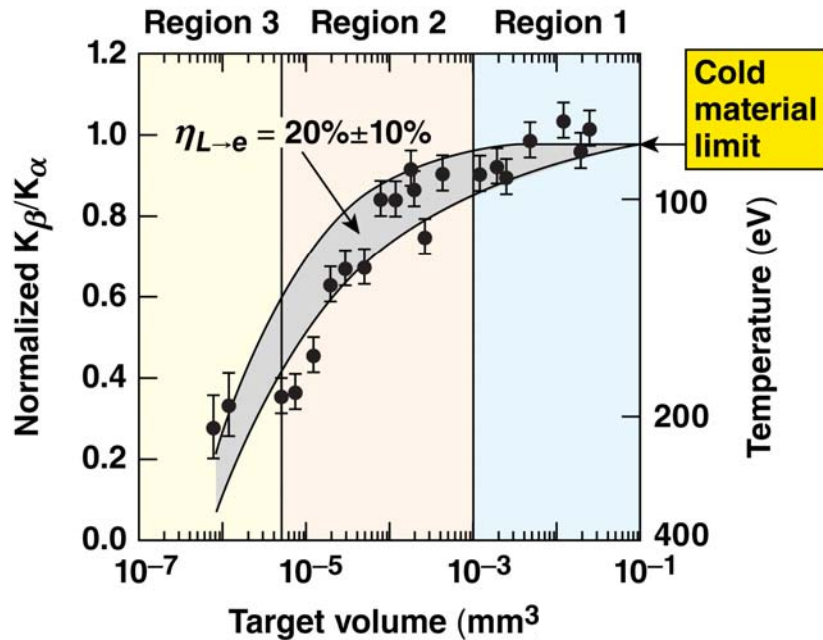
TITAN



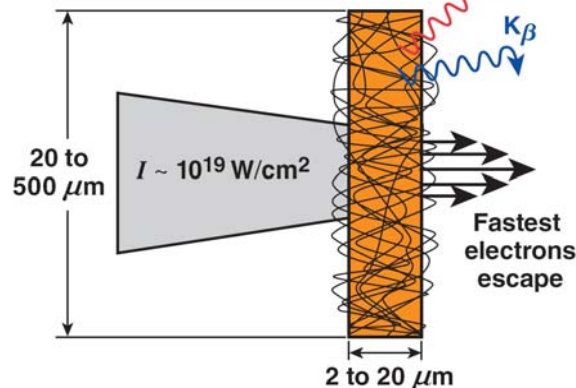
ZPW



Fast electron heating of small mass targets accesses high energy density regimes. Conversion efficiency of laser energy to hot electrons $\sim 20\%$ for $I > 10^{18} \text{ W/cm}^2$



Spider-silk mounted
 $20 \times 20 \times 2 \mu\text{m}^3$
copper target



Intensity (W/cm^2)

FY09-10 plans:
conversion efficiency
for 2.5kJ 10ps on EP
Structured surfaces to
enhance absorption

Light pressure could reduce electron temperature avoiding difficult reduction of electron energy with shorter wavelength lasers

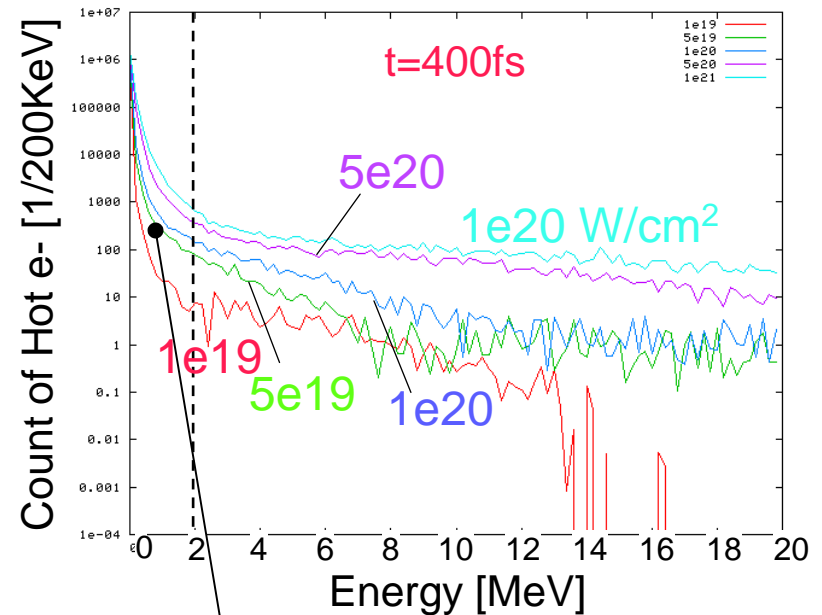
- Early evidence that light pressure effect reduces electron energy
- New diagnostics to measure electron spectrum in the target through bremsstrahlung
- Preliminary results on Titan suggest light pressure effects are significant.

FY09-10 plans:

Improve Brem. diagnostic
Electron energy spectrum
measurements on Titan
and EP



Spectrum observed behind cone.



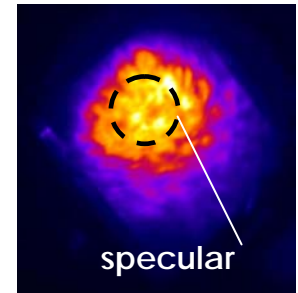
Low energy hot electrons (<2MeV)
increase linearly with intensity.

Improve conversion efficiency through optimum cone design

- **Glancing incidence light on foil simulates cone**
 - Light is efficiently reflected ($\sim 40\%$) but scattered into $\sim f/3$ cone
 - Electron deposition is low and localized - no forward flow



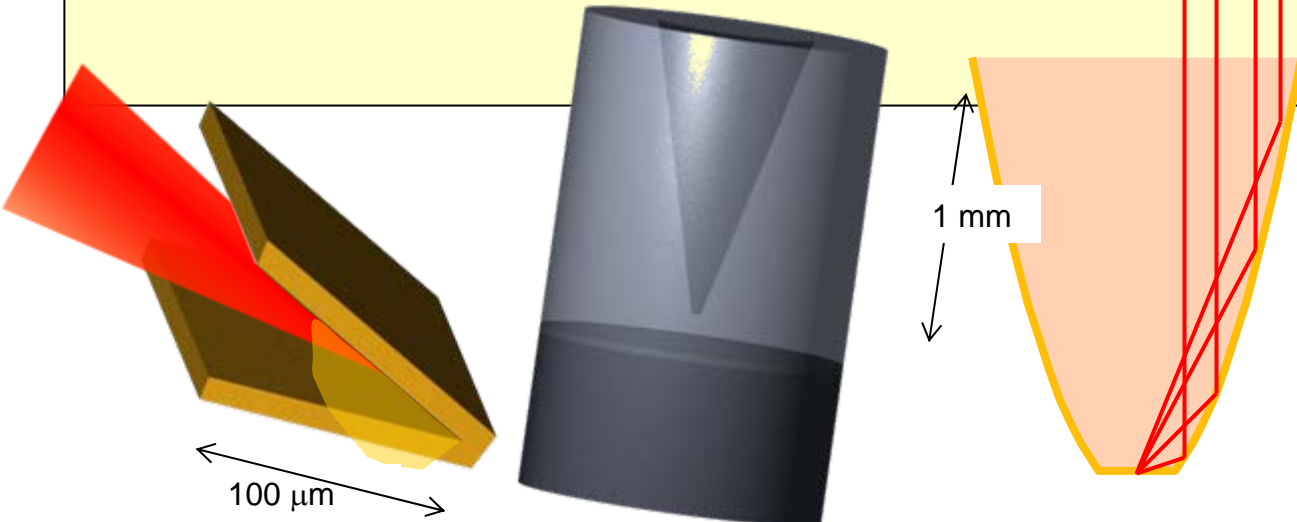
Reflected light beam size somewhat larger than specular



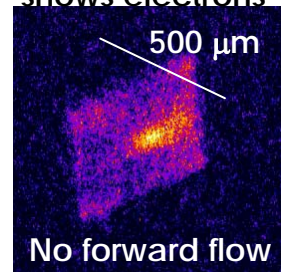
- **FY09-10 Plans**

Optimize cone and cone experiments

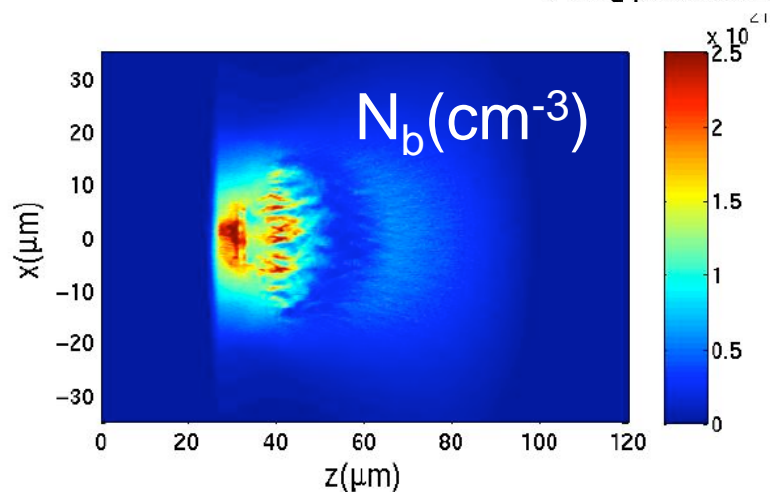
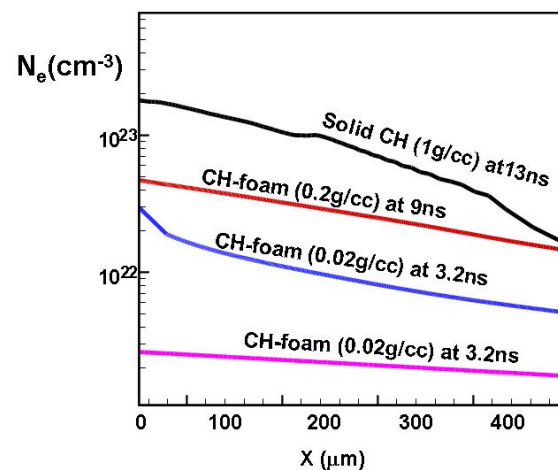
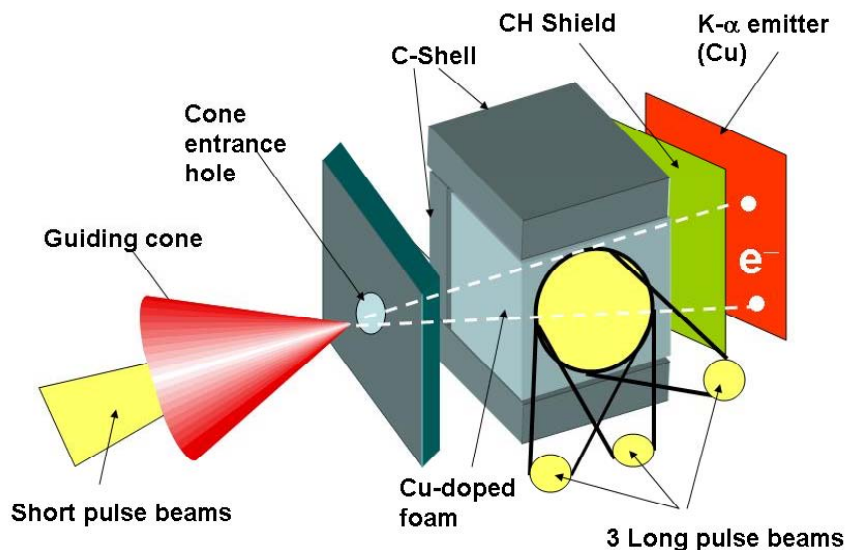
- Paraboloid direct light to tip
- Bury cone in plasma eliminates surface confinement
- Effects of polarization



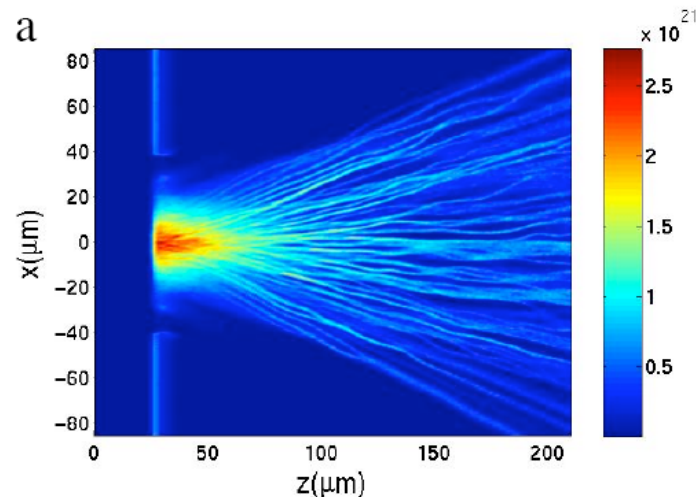
K α fluorescence shows electrons



Plans FY09-10: Proposed EP short pulse experiments in plasmas to study features of FI-relevant electron transport



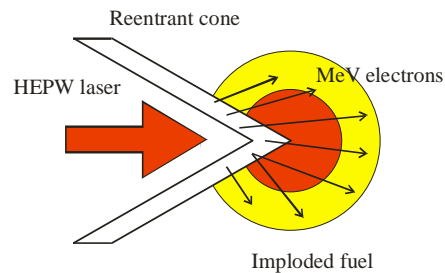
LSP simulation. $N_b=3e21$, $N_p=1e21/cc$
e-transport inhibited by Weibel



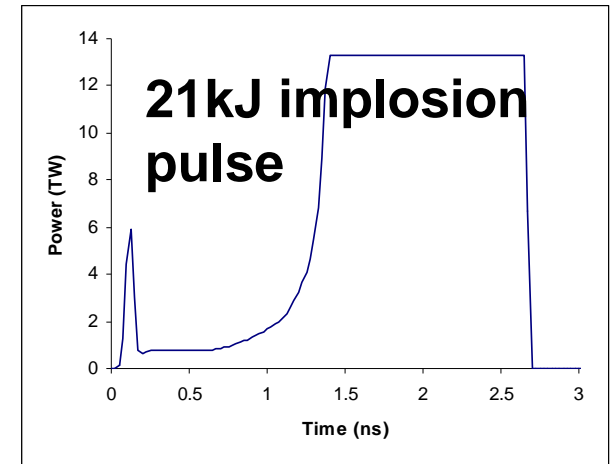
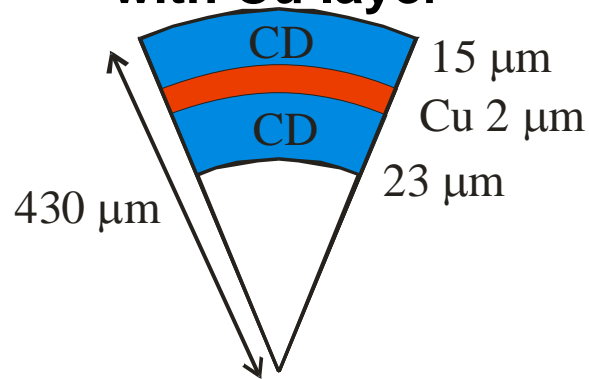
LSP simulation. $N_b=3e21$, $N_p=1e23/cc$
Resistive filamentation

Plans FY09-10: First integrated FI experiments on OMEGA study coupling of fast electrons to the core

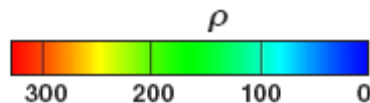
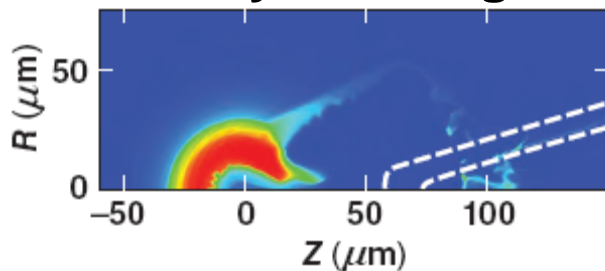
Integrated FI experiment



High ρR target with Cu layer

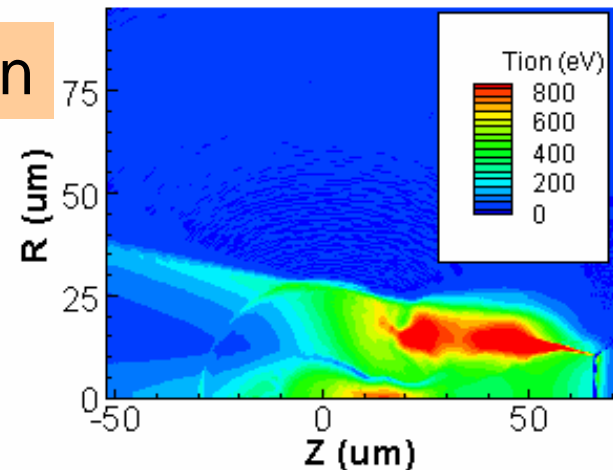


Density to $\sim 100\text{g/cc}$



LSP simulation

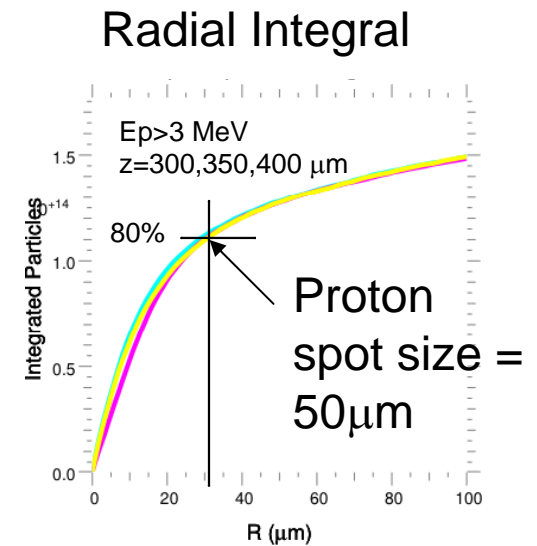
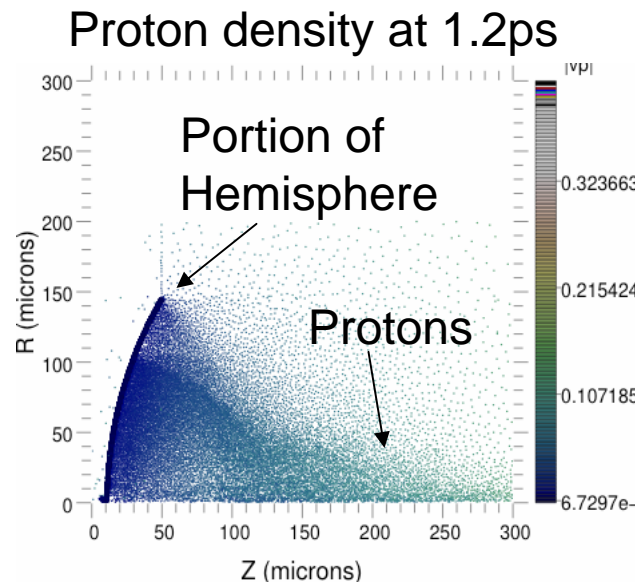
Temperature to $\sim 800\text{eV}$



Proton and light ion fast ignition

- Proton work progressing towards point design by end FY08
- Experimental tests planned for Omega EP in early FY09
- LSP simulations of proton focusing show 80% energy in 50 μ m diameter spot using uniformly illuminated portion of 350 μ m diameter hemisphere
- New proposal including proton and light ion driven fast ignition will be submitted for FY09
- Will provide design for proof of principle proton fast ignition and ion heating experiments by FY12

⇒ Test effect of uniform illumination on proton spot size on Titan in FY08 and Omega EP FY09



Based on initial results from OFES seed grants and other research projects, ion-based fast ignition is very promising

- The requirements for high-gain are well understood
- Quasi-monoenergetic laser-driven ion beams have been demonstrated⁰
- The laser-plasma mechanisms to achieve the required ion energy to penetrate to the fuel core are understood theoretically.¹
- Laser-driven ion-beam are extremely laminar² - focusing possible by shaping the target or by shaping the laser intensity profile.
- Issues to be addressed in FY09-12
 - conversion efficiency
 - control ion-energy spread
 - achieve the required ion energy
 - improve integrated designs
 - field integrated experiments on OMEGA and NIF

*Fernández et al., J. of Physics (2008) in press; ⁰Hegelich et al., Nature **439**, 441 (2006); ¹Yin et al., Phys. Plasmas **14**, 056706 (2007);

²Cowan et al., Phys. Rev. Lett. **92**, 204801 (2004); ³Patel et al., Phys. Rev. Lett. **91**, 125004 (2003)

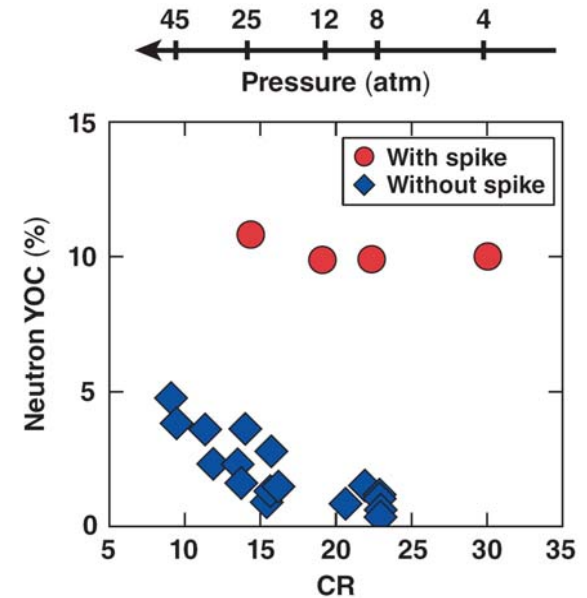
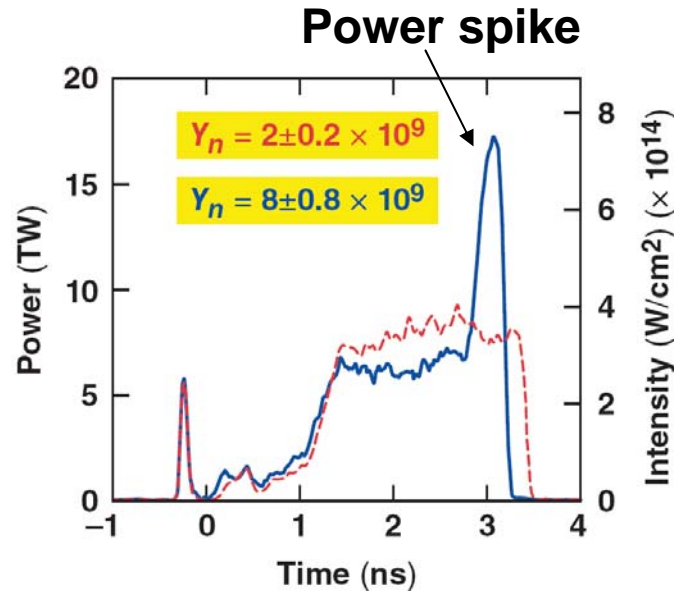
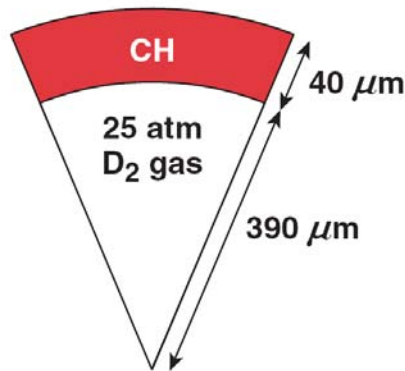
SHOCK IGNITION HIGHLIGHTS and PLANS FOR FY09-10

FESAC priorities – HEDP campaign – Research thrust

Design targets and carry out implosion experiments to identify the optimum assembly of HEDP plasmas at densities of hundreds g/cc.

FY07 shock-ignition experiments on OMEGA have shown improved performance when a shock launching power spike is added at the end of the laser pulse

$E_L = 19 \text{ kJ}$, $\alpha = 1.3$,
 $V_i = 1.7 \times 10^7 \text{ cm/s}$, SSD off



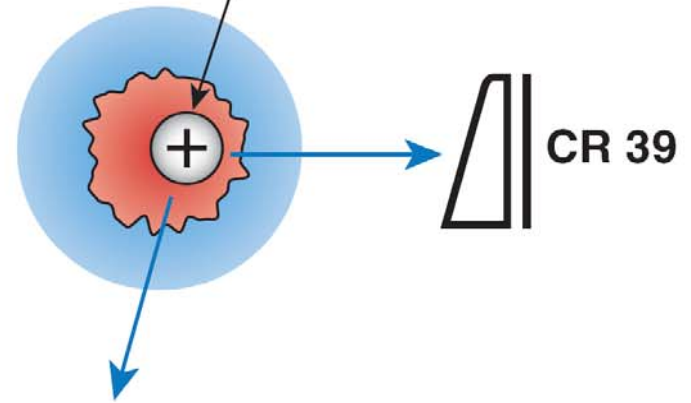
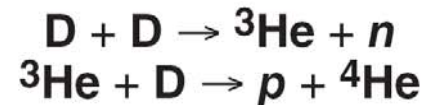
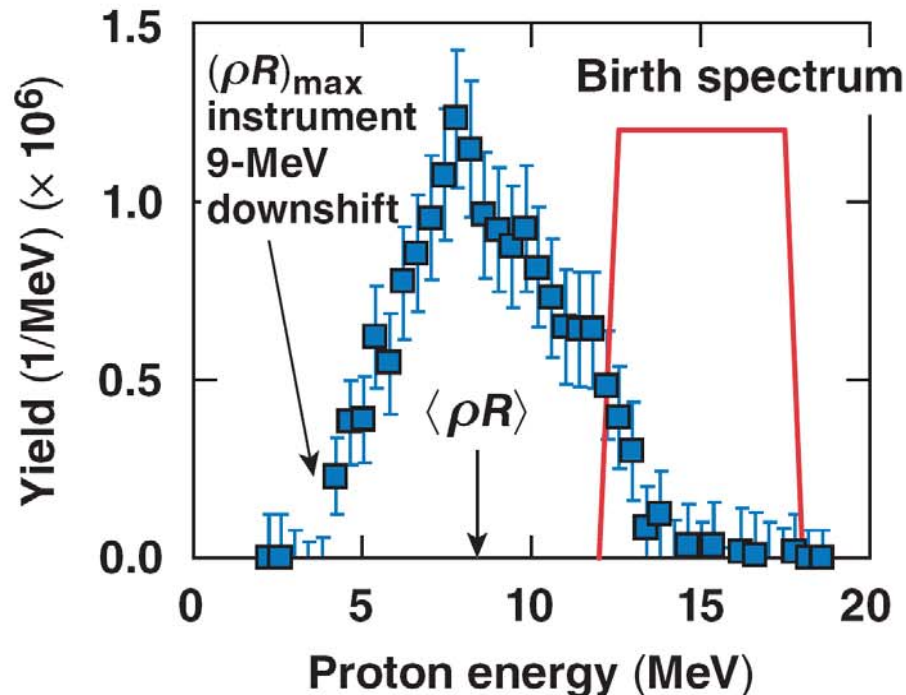
The neutron yield increases considerably when a shock is launched at the end of the pulse.

Shock-Ignition cryogenic-implosion experiments are scheduled for '08-'10

The measured-to-calculated neutron-yield ratios are close to 10% for a hot-spot convergence ratio of 30.

Shock ignition experiments have achieved a peak areal density of 300mg/cm². Highest ρR thus far.

Shot 48674, $E_L = 18.0$ kJ, D₂ 8.3 atm

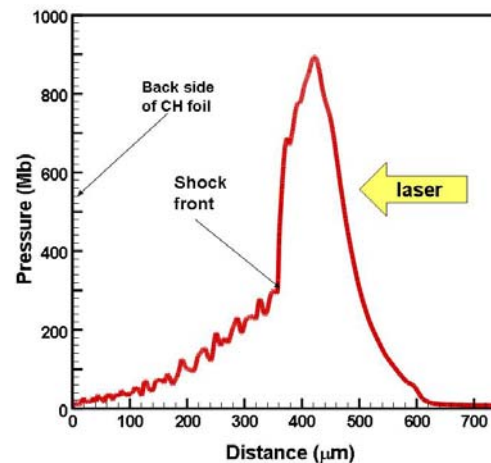
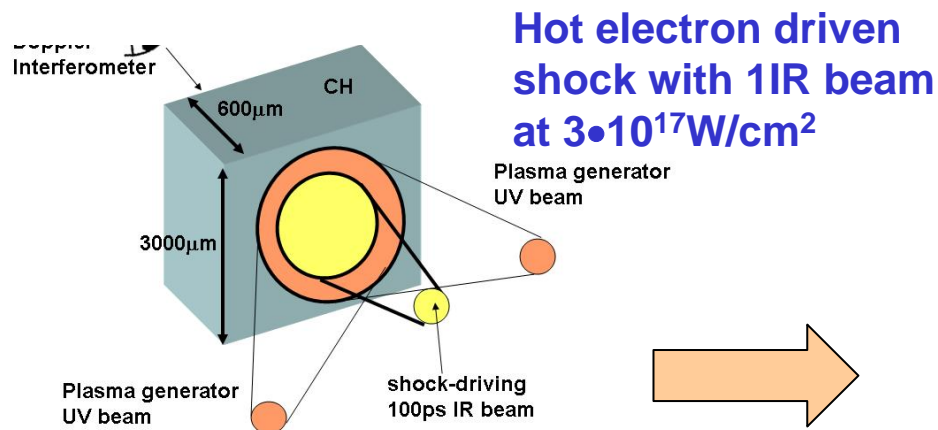
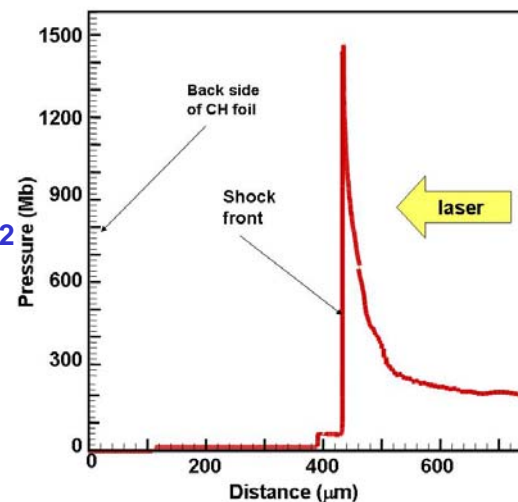
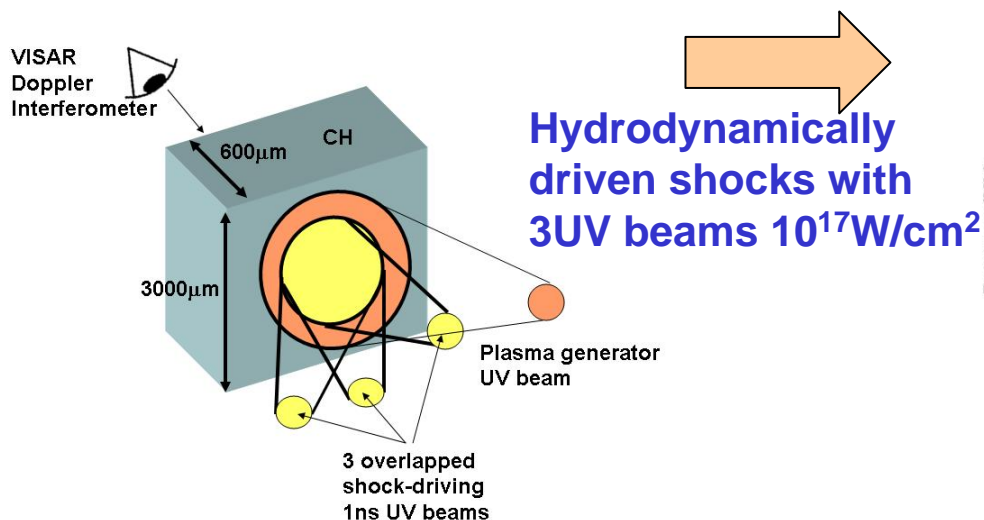


~9-MeV downshift

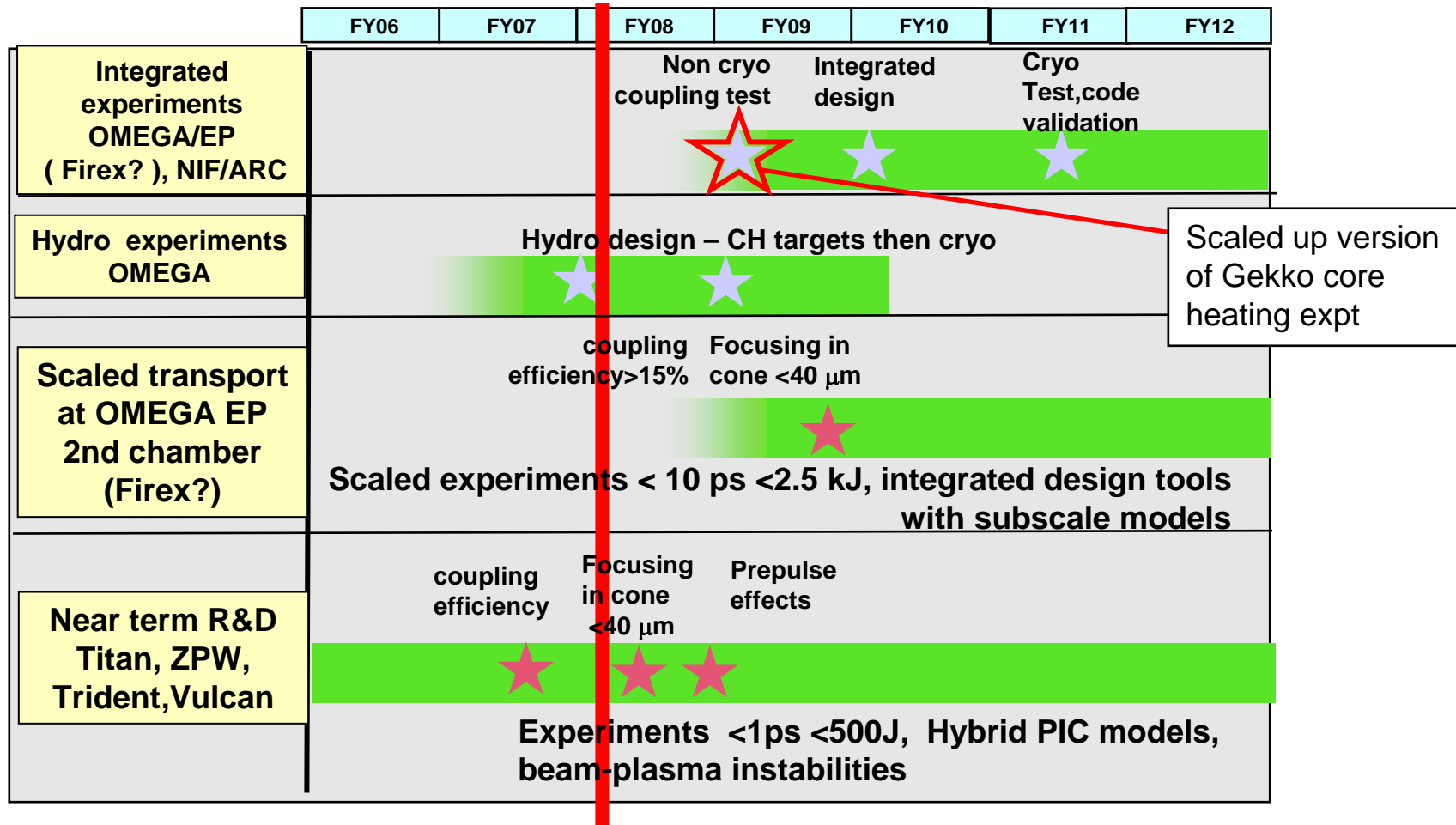
$$\begin{aligned} (\rho R)_{\text{max}} &> 0.3 \text{ g/cm}^2 \\ \langle \rho R \rangle &= 0.2 \text{ g/cm}^2 \end{aligned}$$

Plans for FY09-10: OMEGA-EP experiments to generate ultra-strong shocks > 100Mbar

Proposed '09-'10 experiments on EP

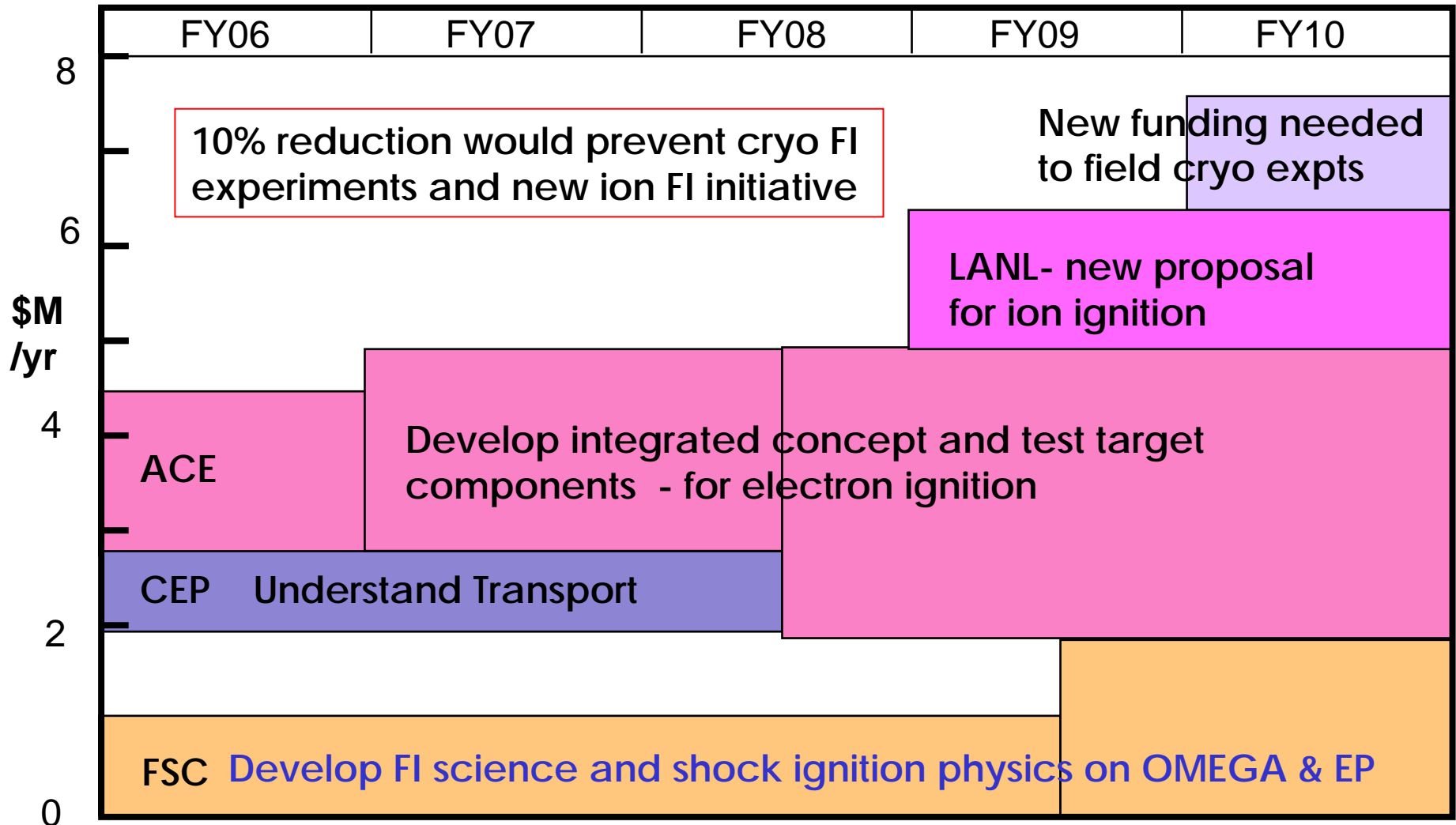


Plan is phased to match availability of facilities - culminates in integrated designs and experiments



⇒ Will define design parameters for initial shots on OMEGA EP

FI program budget



In FY11 the program will transition to integrated experiments testing point designs on OMEGA EP and NIF-ARC